$\mathbf{SU(3)}_L \otimes \mathbf{U(1)}_N$ MODEL FOR RIGHT-HANDED NEUTRINO NEUTRAL CURRENTS

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Abstract

A model based on the $\mathrm{SU}(3)_L \otimes \mathrm{U}(1)_N$ gauge group, in which neutrinos have right-handed neutral currents is considered. We argue that in order to have a result consistent with low-energy one, the right-handed neutrino component must be treated as correction instead of an equivalent spin state.

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For a long time, neutrino is one of the most attracted subjects in particle physics. It is well known that in the standard model (SM) neutrinos have only left-handed (LH) currents. Whether neutrinos have right-handed (RH) currents is still an unresolved question.

Recently, RH neutrino currents have been included in a model based on the $SU(3)_C \otimes SU(3)_L \otimes U(1)_N$ gauge group [1]. However, by some reasons, consequences of this model (model I as called in [1]) are too different from those of the SM. For example, *the magnitude of the neutral couplings of the right-handed neutrinos coincides with that of the left-handed neutrinos in the SM* (see Eqs.(44,51) in [1]). If so, in order to get results consistent with low energy phenomenology such as $\nu_\mu - e$ and $\bar{\nu}_\mu - e$ scatterings, $g_L(e)$ must be replaced by $g_R(e)$ and vice versa [2]. It is obvious that this statement is unacceptable.

It is to be noted that a similar model has been proposed in [3] (for details see [4]) in which RH neutrinos by opposition to our model, give contribution to neutral currents of the LH neutrinos. The purpose of this report is to briefly present the model (for more details in this model, the reader can find in [5]).

Our model deals with nine leptons and nine quarks. There are three left- and right-handed neutrinos $(\nu_e, \nu_\mu, \nu_\tau)$, three charged leptons (e, μ, τ), four quarks with charge 2/3, and five quarks with charge -1/3. Fermion content of this model is almost the same as in [4] with the unique change in a bottom of the lepton triplets

$$f^a_L = \begin{pmatrix} \nu^a_L \\ e^a_L \\ (\nu^c_L)^a \end{pmatrix} \sim (1, 3, -1/3), e^a_R \sim (1, 1, -1), \tag{1}$$

where a = 1, 2, 3 is the generation index.

Two of the three quark generations transform identically and one generation transforms in a different representation:

$$Q_{iL} = \begin{pmatrix} d_{iL} \\ -u_{iL} \\ d'_{iL} \end{pmatrix} \sim (3, \bar{3}, 0), \tag{2}$$

$$u_{iR} \sim (3, 1, 2/3), d_{iR} \sim (3, 1, -1/3), d'_{iR} \sim (3, 1, -1/3),\ \ i = 1, 2,$$

$$Q_{3L} = \begin{pmatrix} u_{3L} \\ d_{3L} \\ T_L \end{pmatrix} \sim (3, 3, 1/3),$$

$$u_{3R} \sim (3, 1, 2/3), d_{3R} \sim (3, 1, -1/3), T_R \sim (3, 1, 2/3).$$

Fermion mass generation and symmetry breaking can be achieved with just three $SU(3)_L$ triplets:

$$\chi \sim (1, 3, -1/3),\ \ \rho \sim (1, 3, 2/3),\ \ \eta \sim (1, 3, -1/3),$$

with the following vacuum expectation values (VEVs): $\langle\chi\rangle^T = (0, 0, \omega/\sqrt{2})$, $\langle\rho\rangle^T = (0, u/\sqrt{2}, 0)$, $\langle\eta\rangle^T = (v/\sqrt{2}, 0, 0)$. In the present model the neutrinos remain massless at the tree level, and by radiative corrections they will gain masses [6]. In this model, the exotic quarks carry electric charges 2/3 and -1/3, respectively, similarly to ordinary quarks. Consequently, the exotic quarks can mix with the ordinary ones. This type of mixing gives the flavor changing neutral currents and has been discussed in Ref. [7].

By identifying $\sqrt{2}W^+_\mu = W^1_\mu - iW^2_\mu, \sqrt{2}Y^-_\mu = W^6_\mu - iW^7_\mu, \sqrt{2}X^o_\mu = W^4_\mu - iW^5_\mu$, the interactions among the charged vector fields with leptons are

$$\begin{aligned}\mathcal{L}^{CC}_l &= -\frac{g}{\sqrt{2}}(\bar{\nu}^a_L\gamma^\mu e^a_L W^+_\mu + \bar{(\nu^c_L)}^a\gamma^\mu e^a_L Y^+_\mu \\ &\quad +\bar{\nu}^a_L\gamma^\mu(\nu^c_L)^a X^0_\mu + \text{h.c.}).\end{aligned} \tag{3}$$

For the quarks we have

$$\begin{aligned}\mathcal{L}^{CC}_q &= -\frac{g}{\sqrt{2}}[(\bar{u}_{3L}\gamma^\mu d_{3L} + \bar{u}_{iL}\gamma^\mu d_{iL})W^+_\mu + (\bar{T}_L\gamma^\mu d_{3L} + \bar{u}_{iL}\gamma^\mu d'_{iL})Y^+_\mu \\ &\quad +(\bar{u}_{3L}\gamma^\mu T_L - \bar{d'}_{iL}\gamma^\mu d_{iL})X^0_\mu + \text{h.c.}].\end{aligned} \tag{4}$$

¿From (3) and (4), it follows that the interactions with the Y^+ and X^0 bosons violate the lepton number and the weak isospin .

The physical neutral gauge bosons are defined through the mixing angle ϕ and Z, Z':

$$\begin{aligned}Z^1 &= Z\cos\phi - Z'\sin\phi, \\ Z^2 &= Z\sin\phi + Z'\cos\phi,\end{aligned} \tag{5}$$

where the photon field A_μ and Z, Z' are given by [4]:

$$\begin{aligned}A_\mu &= s_W W^3_\mu + c_W\left(-\frac{t_W}{\sqrt{3}}\, W^8_\mu + \sqrt{1-\frac{t^2_W}{3}}\, B_\mu\right), \\ Z_\mu &= c_W W^3_\mu + s_W\left(-\frac{t_W}{\sqrt{3}}\, W^8_\mu + \sqrt{1-\frac{t^2_W}{3}}\, B_\mu\right), \\ Z'_\mu &= \sqrt{1-\frac{t^2_W}{3}}\, W^8_\mu + \frac{t_W}{\sqrt{3}}\, B_\mu.\end{aligned} \tag{6}$$

The neutral current interactions can be written in the form

$$\begin{aligned}\mathcal{L}^{NC} &= \frac{g}{2c_W}\Big\{\bar{f}\gamma^\mu[a_{1L}(f)(1-\gamma_5) + a_{1R}(f)(1+\gamma_5)]fZ^1_\mu \\ &\quad + \bar{f}\gamma^\mu[a_{2L}(f)(1-\gamma_5) + a_{2R}(f)(1+\gamma_5)]fZ^2_\mu\Big\}.\end{aligned} \tag{7}$$

Using $\bar{\nu}_L^c \gamma^\mu \nu_L^c = -\bar{\nu}_R \gamma^\mu \nu_R$ we see that in this model the neutrinos have both left- and right-handed neutral currents:

$$
\begin{aligned}
a_{1L}(\nu) &= \frac{1}{2}\left(\cos\phi + \frac{1-2s_W^2}{\sqrt{3-4s_W^2}}\sin\phi\right),\ a_{1R}(\nu) = \frac{c_W^2}{\sqrt{3-4s_W^2}}\ \sin\phi, \\
a_{2L}(\nu) &= \frac{1}{2}\left(\sin\phi - \frac{1-2s_W^2}{\sqrt{3-4s_W^2}}\cos\phi\right),\ a_{2R}(\nu) = -\frac{c_W^2}{\sqrt{3-4s_W^2}}\ \cos\phi. \qquad (8)
\end{aligned}
$$

¿From the above formulas, we see that coupling of the RH neutrino neutral current with Z^1 is very weak because of its linear dependence on $\sin\phi$.

The data from the Z-decay allow us to fix the limit for ϕ as [5] $-0.00285 \leq \phi \leq 0.00018$. As in Ref. [4], with this mixing angle, R_b in this model still disagrees with the recent experimental value $R_b = 0.2192 \pm 0.0018$ measured at LEP.

To get constraint on the new neutral gauge boson mass M_{Z^2} we consider neutrino-electron scatterings. Since in this model neutrinos have both left- and right-handed currents, the effective four-fermion interactions relevant to ν-fermion neutral current processes, are presented as:

$$
\begin{aligned}
-\mathcal{L}_{eff}^{\nu f} &= \frac{2\rho_1 G_F}{\sqrt{2}}\Big\{g_{1V}(\nu)\bar{\nu}\gamma_\mu(1-r\gamma_5)\nu\bar{f}\gamma^\mu[g_{1V}(f)-g_{1A}(f)\gamma_5]f \\
&\quad + \xi g_{2V}(\nu)\bar{\nu}\gamma_\mu(1-r'\gamma_5)\nu\bar{f}\gamma^\mu[g_{2V}(f)-g_{2A}(f)\gamma_5]f\Big\}, \qquad (9)
\end{aligned}
$$

where $\xi = \frac{M_{Z_1}^2}{M_{Z_2}^2}$, and $r = \frac{g_{1A}(\nu)}{g_{1V}(\nu)}, r' = \frac{g_{2A}(\nu)}{g_{2V}(\nu)}$ are *right-handedness* of currents.

The Feynman amplitude for the $\nu_\mu - e$ scattering is

$$
\begin{aligned}
T_{if} &= \frac{2\rho_1 G_F}{\sqrt{2}}\{\bar{\nu}(k')\gamma_\mu(1-r\gamma_5)\nu(k)\bar{e}(p')\gamma^\mu[g_{1V}(\nu)g_{1V}(e)-g_{1V}(\nu)g_{1A}(e)\gamma_5]e(p) \\
&\quad + \xi\bar{\nu}(k')\gamma_\mu(1-r'\gamma_5)\nu(k)\bar{e}(p')\gamma^\mu[g_{2V}(\nu)g_{2V}(e)-g_{2V}(\nu)g_{2A}(e)\gamma_5]e(p)\}. \qquad (10)
\end{aligned}
$$

As in Ref. [8] in the laboratory reference frame ($\vec{p}_e = 0$), the cross section is given:

$$
\frac{d\sigma(\nu_\mu e)}{dE_e} = \frac{1}{32\pi m_e E_\nu^2}\left(\frac{1}{2.s}\sum|M|^2\right), \qquad (11)
$$

where E_ν, E_e are the initial neutrino and final electron energies and s is the number of the neutrino states. Perform the usual manipulations [8], we get finally

$$
\begin{aligned}
\sigma(\nu_\mu e) &= \frac{\rho_1^2 m_e E_\nu G_F^2}{s\pi}\left[(I^e+J^e)+\frac{1}{3}(I^e-J^e)\right], \\
\sigma(\bar{\nu}_\mu e) &= \frac{\rho_1^2 m_e E_\nu G_F^2}{s\pi}\left[\frac{1}{3}(I^e+J^e)+(I^e-J^e)\right], \qquad (12)
\end{aligned}
$$

where

$$
\begin{aligned}
I^e &= g_{1V}^2(\nu)[g_{1V}^2(e)+g_{1A}^2(e)](1+r^2)+2\xi g_{1V}(\nu)g_{2V}(\nu)[g_{1V}(e)g_{2V}(e)+g_{1A}(e)g_{2A}(e)]\\
&\quad\times(1+rr')+\xi^2 g_{2V}^2(\nu)[g_{2V}^2(e)+g_{2A}^2(e)](1+r^{,2}),\\
J^e &= 4rg_{1V}^2(\nu)g_{1V}(e)g_{1A}(e)+2\xi(r+r')g_{1V}(\nu)g_{2V}(\nu)[g_{1V}(e)g_{2A}(e)+g_{1A}(e)g_{2V}(e)]\\
&\quad+4\xi^2 r' g_{2V}^2(\nu)g_{2V}(e)g_{2A}(e).
\end{aligned}
\tag{13}
$$

It is easy to see that for $r=1$ and $\xi=0, I^e$ and J^e become, respectively,

$$
\begin{aligned}
I^e &= 2g_{1V}^2(\nu)[g_{1V}^2(e)+g_{1A}^2(e)],\\
J^e &= 4g_{1V}^2(\nu)g_{1V}(e)g_{1A}(e).
\end{aligned}
\tag{14}
$$

Thus, it is straightforward to see that if s=1 the cross sections in (12) get the SM forms [8].

Substituting coupling constants into Eqs.(12), we finally get

$$
\begin{aligned}
\sigma(\nu_\mu e) &= \frac{\rho_1^2 m_e E_\nu G_F^2}{s6\pi}\left(\cos 2\phi+\frac{1-2s_W^2}{\sqrt{3-4s_W^2}}\sin 2\phi\right)^2\\
&\quad\times\left\{(1-4s_W^2+8s_W^4)[(1-\xi)^2+(r-\xi r')^2]\right.\\
&\quad\left.+(1-4s_W^2)(1-\xi)(r-\xi r')\right\},
\end{aligned}
\tag{15}
$$

$$
\begin{aligned}
\sigma(\bar\nu_\mu e) &= \frac{\rho_1^2 m_e E_\nu G_F^2}{s6\pi}\left(\cos 2\phi+\frac{1-2s_W^2}{\sqrt{3-4s_W^2}}\sin 2\phi\right)^2\\
&\quad\times\left\{(1-4s_W^2+8s_W^4)[(1-\xi)^2+(r-\xi r')^2]\right.\\
&\quad\left.-(1-4s_W^2)(1-\xi)(r-\xi r')\right\}.
\end{aligned}
\tag{16}
$$

¿From Eqs.(15, 16), we see that when $\xi=0$, $\phi=0$, and $r=r'=1$, the low-energy SM results are recovered if and only if $s=1$. Note that the formulas (15, 16) are applicable for the theories with one extra neutral gauge boson Z^2 and neutrinos having left- and right-handed components.

For our model, r, r' have the forms:

$$
\begin{aligned}
r(\nu) &\simeq 1-\frac{4c_W^2}{\sqrt{3-4s_W^2}}\tan\phi+O(\tan^2\phi),\\
r'(\nu) &\simeq -\frac{1}{3-4s_W^2}\left(1+\frac{4c_W^2}{\sqrt{3-4s_W^2}}\tan\phi\right)+O(\tan^2\phi).
\end{aligned}
\tag{17}
$$

Thus, Eqs.(15, 16) have only two variables ϕ and ξ. Moreover, ϕ has been determined by the Z decay data, consequently ξ can be fixed by the neutrino- electron scatterings.

A fit to experimental data [9] gives a limit for the mass of the Z^2 boson $M_{Z^2} \geq 320$ GeV.

We have presented the 331 model with neutrino right-handed currents. The main features of this model may be summarized as follows: Fermion mass generation and symmetry breaking can be achieved with just three Higgs triplets. The neutrinos, however, remain massless at the tree level. The lepton number and the weak isospin are violated in both the heavy charged gauge boson sector and in the Higgs sector. We have shown that in order to get the low energy SM result, right-handed component of neutrinos in this model has to be considered as a correction instead of an equivalent spin state (spin-average factors of $\frac{1}{2}$).

Because of the $Z-Z'$ mixing, there is a modification to the Z^1 coupling proportional to $\sin\phi$, and the Z-decay gives $-0.00285 \leq \phi \leq 0.00018$. The data from neutrino neutral current elastic scatterings shows that mass of the new neutral gauge boson M_{Z^2} is in the range of 400 GeV, and from the symmetry-breaking hierarchy we get: $M_{Y^+} \simeq M_{X^o} \simeq 0.72 M_{Z^2} \geq 290$ GeV.

As the other 331 versions, the model is only anomaly free if the number of generations is a multiple of three, and the third generation has been treated differently from the first two. With many unique proporties, this model deserves our attention and further study.

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